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SOLVENT EFFECT IN THE FORMATION OF SCHIFF BASES

By

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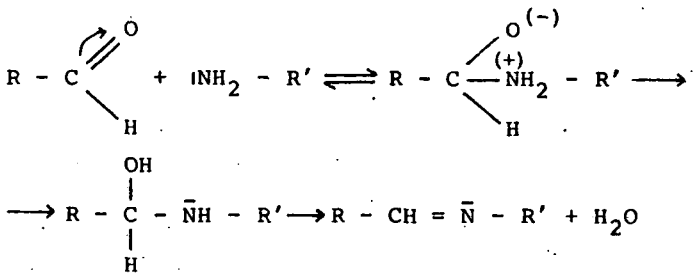
The formation of substituted N-(benzylidene)anilines was studied in various solvent mixtures. For compounds containing an OH group in the o- or p-position on the aldehyde ring, good correlations were found between log k and the E_T^N and B_{KT} values of the solvent mixtures, and between log k and the activity coefficient of the more polar solvent component.

Introduction

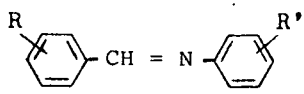
Since Schiff bases are of importance from both theoretical and practical aspects, they have been studied widely. The condensation of aromatic aldehydes and aromatic amines is particularly suitable for the kinetic study of their formation. Kresze and his coworkers [1-3] reported that the mechanism of the kinetically second order process is as follows:



On the basis of this mechanism, it can be expected, that the reaction will be accelerated by any factor which reduces the electron density on the carbonyl carbon atom or increases the electron density on the nitrogen atom. This was earlier confirmed by studies of the effects of the substituents on the aldehyde and amine components [4, 5]. Previous solvent effect results also accord fully with the presumed mechanism [6]. The present paper reports on a study of the rates of formation of some Schiff bases as functions of the acidity and basicity parameters (E_T^N and B_{KT}) of various solvent mixtures and the activity coefficients of the solvent components. This study was intended to clarify details of the solvent effect and the connection between the solvent effect and the substituents. This method has already been applied with good results in investigations of the amine exchange and hydrolysis of Schiff bases [7, 8].

Experimental

The formations of the following Schiff bases were studied:



1	R = 2-OH,	R' = H
2	R = 2-OH,	R' = 4-CH_3
3	R = 2-OH,	R' = 4-OCH_3
4	R = 4-OH,	R' = 4-OCH_3
5	R = 4-CH_3,	R' = 4-CH_3
6	R = 4-OCH_3,	R' = 4-CH_3

The Schiff bases, aldehydes and amines used for the kinetic measurements were purified by recrystallization or distillation, and their purities were then checked via melting point and boiling point measurements and determination of the absorption curves. The organic solvents applied were purified by means of the methods customary in spectroscopy, and were carefully freed from water. Bidistilled water was used to prepare the alcohol-water solvent mixtures. The reactants were used in 10^{-3}-10^{-2} mol/dm^3 concentration and the reactions were followed spectrophotometrically at 298 K. The rate constants $dm^3.mol^{-1}.min^{-1}$ were calculated for second-order reactions. For mixtures containing water, the reverse reaction (hydrolysis) was also taken into consideration.

The acidities of the solvents were characterized in terms of the Reichard parameter E_T^N [9], and their basicities in terms of the modified Kamlet-Taft parameter B_{KT} [10, 11]. These parameters were determined earlier [12].

Results and discussion

Rate constants determined in various solvent mixtures are given in Tables I-III, which list the E_T^N and B_{KT} values of the solvent mixtures, and the activity coefficients (γ) of one or both components.

Similarly as in investigations of the amine exchange and hydrolysis of Schiff bases [7, 8], the following equation was applied to describe the correlation between the rate constant and the solvent parameters:

$$\log k = b_1 E_T^N + b_2 B_{KT} + a \qquad (1)$$

The data in Tables I-III were employed with the method of least squares to determine the constants (b_1, b_2 and a) in Eq. (1), and the multiple correlation coefficient (R) was calculated. For a better comparison of the effects of acidity and basicity, the regression coefficients b_1 and b_2 were converted to beta coefficients β_1 and β_2, these were normalized [18, 7], and the distribution of the effects of acidity and basicity (β_1' and β_2') was obtained in percentages for the reaction in question. The calculated values are listed in Table IV.

Similarly as in investigations of amine exchange [19], the following relationship was applied to characterize the connection between the rate of formation and the composition of the solvent mixture:

$$\log k = x_1 \log k_1^* + x_2 \log k_2^* + B x_1 x_2 \qquad (2)$$

Table I

Rates of formation of Schiff bases (1-6) in ethanol(1)-benzene(2) solvent mixture

T = 298 K

x_1	γ_1 [13]	γ_2 [13]	E_T^N [12]	B_{KT} [12]	log k + 4					
					1	2	3	4	5	6
0.000	-	1.00	0.127	0.08	0.477	0.869	1.204	-	0.556	0.146
0.145	3.70	1.12	0.428	0.34	2.079	2.462	2.875	-	0.653	0.301
0.276	2.25	1.29	0.470	0.50	2.362	2.748	3.176	1.720	0.752	0.447
0.395	1.71	1.45	0.501	0.56	2.562	2.929	3.326	1.879	0.851	0.580
0.604	1.25	2.06	0.548	0.64	2.816	3.193	3.577	2.025	1.041	0.799
0.781	1.06	2.80	0.584	0.70	2.997	3.377	3.769	2.312	1.243	1.013
0.932	1.02	3.92	0.633	0.77	3.173	3.556	3.929	2.596	1.562	1.255
1.000	1.00	-	0.655	0.78	3.255	3.638	4.009	2.734	1.785	1.398

Table II

Rates of formation of Schiff bases (1-3) in ethanol (1)-acetone(2) solvent mixture

T = 298 K

x_1	γ_1 [15]	E_T^N [14]	B_{KT} [14]	log k + 4		
				1	2	3
0.000	-	0.355	0.54	1.114	1.591	1.875
0.123	1.67	0.537	0.55	1.544	1.993	2.398
0.240	2.52	0.580	0.56	1.836	2.305	2.663
0.352	1.40	0.610	0.58	2.009	2.484	2.863
0.558	1.21	0.634	0.61	2.336	2.794	3.188
0.746	1.10	0.643	0.65	2.653	3.117	3.477
0.920	1.03	0.647	0.70	3.045	3.455	3.813
1.000	1.00	0.650	0.77	3.255	3.638	4.009

B values were calculated from the data in Tables I-III, and a study was made as to whether the relationship established for amine exchange [19] was also valid in this case:

$$B = b\,\gamma_1 + a \qquad (3)$$

Values of a and b calculated with the method of least squares for the reactions in question, together with the correlation coefficients (r), are to be found in Table V.

Table III

Rates of formation of N-(2-hydroxybenzylidene)4'-methyl-aniline in water(1)-methanol(2) solvent mixture

T = 298 K

x_1	γ_1 [17]	E_T^N [16]	B_{KT} [16]	log k + 1
0.000	-	0.77	0.62	0.806
0.195	1.19	0.78	0.54	0.991
0.350	1.14	0.79	0.55	1.176
0.477	1.06	0.81	0.53	1.346
0.584	0.97	0.82	0.50	1.519
0.756	0.83	0.86	0.39	1.833
0.830	0.78	0.89	0.34	2.000
1.000	1.00	1.00	0.19	2.450*

* extrapolated value

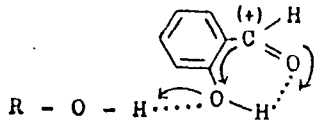
The data in Table IV reveal that Eq. (1) satisfactorily describes the solvent effect in the formation of Schiff bases (1-4) which contain an OH group in the o- or p-position on the aldehyde ring. For the 2-hydroxy derivatives (1-3) in ethanol-benzene, the rate of formation is decisively (94-96 %) influenced by the acidity of the solvent. This can be interpreted in that the OH group in the o-position is intramolecularly hydrogen-bonded here too, and thus the alcohol molecules can interact with it only as hydrogen donors. On the other hand, this interaction greatly increases the positiveness of the azomethine carbon atom and hence the rate

Table IV

Application of equation (1) to the formation of Schiff bases in different solvent mixtures

Solvent mixture	Schiff base	b_1	b_2	a	β_1'(%)	β_2'(%)	n	R
ethanol--benzene	1	5.093	0.193	-4.152	94.87	5.13	8	0.9984
	2	5.061	0.201	-3.759	94.64	5.36	8	0.9986
	3	5.631	-0.162	-3.456	96.04	3.96	8	0.9976
	4	8.967	-2.229	-5.389	72.12	27.88	8	0.9954
	5	-2.066	3.014	-3.572	32.44	67.56	8	0.8785
	6	-2.125	3.197	-3.956	31.77	68.23	8	0.9336
ethanol--acetone	1	2.829	6.372	-7.373	35.22	64.78	8	0.9934
	2	2.887	5.955	-6.701	37.25	62.75	8	0.9915
	3	3.272	5.723	-6.417	41.19	58.81	8	0.9944
water--methanol	2	9.153	-0.264	-6.967	93.98	6.02	7	0.9820

of the reaction.



(The interaction between the oxo group and the alcohol can be neglected in comparison with this, but the rate of the reaction is several orders lower in the absence of the 2OH group.) For the 4-hydroxy derivative, the acidity function

Table V

Application of equation (3) to the formation of Schiff bases in different solvent mixtures

Solvent mixture	Schiff base	b	a	n	r
ethanol-benzene	1	2.911	-1.016	6	0.9985
	2	2.901	-1.037	6	0.9987
	3	3.089	-1.123	6	0.9986
	5	0.420	-1.943	6	0.7074
	6	0.195	-0.805	6	0.7093
ethanol-acetone	1	3.261	-3.879	6	0.9983
	2	2.669	-2.969	6	0.9934
	3	4.004	-4.431	6	0.9922
water-methanol	2	0.840	-1.859	6	0.9950

of the solvent decreases and its basicity function increases, and the latter hinders the reaction ($b_2 < 0$). The reason for this is probably that alcohol molecules can interact with the OH group in the p-position either as H-donors or as H-acceptors. However, the latter hydrogen-bond decreases the positiveness of the azomethine carbon atom and hence does not promote the reaction.

Naturally, in the examined reactions the interaction between the amine component and the solvent must also be taken into account. The alcohol molecules can form hydrogen--bonds by reacting as either H-donors or H-acceptors with the amino groups, with resulting opposite influences on the nucleophilic nature of the nitrogen atom. Since the

-O-H·····N$\leqslant$ bond is the stronger, the acidity of the solvent can be the more important from the aspect of formation of the Schiff base, hindering the reaction. However, this effect is unimportant if the aldehyde molecules contain OH groups in the o- or p-position, because the rate-increasing effects of these are considerably higher.

The situation changes if the aldehyde component does not contain an OH group in the o- or p-position. In this case the rate of the reaction is considerably lower and thus the importance of the effect of the hydrogen-bond formed with the oxo or amino group increases. However, the acidity of the solvent influences the reactivities of the aldehyde and amine components in opposite ways. This presumably explains why Eq. (1) yields a very poor correlation for compounds 5 and 6 ($R = 0.8785$ and $R = 0.9336$).

There are very good correlations for compounds 1-3 in ethanol-acetone, but the effect of the acidity of the solvent greatly decreases and the effect of its basicity increases. In our opinion this is caused by hydrogen-bond formation between ethanol and acetone or between amine and acetone. The former hinders the interaction between ethanol and aldehyde, but the latter increases the electron density on the amine-nitrogen and hence the rate of the reaction. In water-methanol, the acidity of the solvent also has a decisive role.

For the formation of Schiff bases (1-3) which contain an OH group in the o-position on the aldehyde molecule, a very good correlation was found with both Eq. (2) and Eq. (3) (Table V), similarly as in the amine exchange of Schiff bases [19]. However, when there are $-CH_3$ or $-OCH_3$ substituents instead of -OH in the molecule, the correlation is very bad. It is interesting that for these compounds $B < 0$

in Eq. (2), as log k measured in the mixture is lower than would follow from the additivity; each solvent component mutually "spoils" the effect of the other. For compounds 1-3, B is positive; in the mixture log k is higher than corresponds to additivity. This is illustrated in Figures 1 and 2.

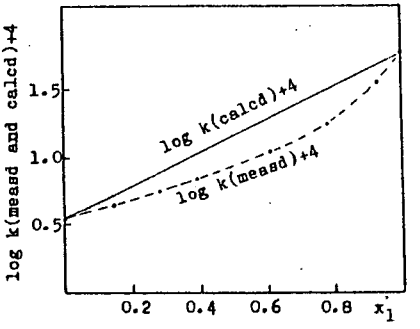


Figure 1.: Deviation of the formation rate of compound 5 from the additivity in ethanol-benzene solvent mixture

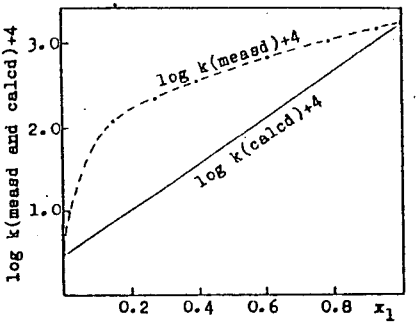


Figure 2.: Deviation of the formation rate of compound 1 from the additivity in ethanol-benzene solvent mixture

In our opinion the explanation of the above finding is as follows: since the association of ethanol molecules decreases in ethanol-benzene, the number of "free" alcohol molecules will be comparatively higher. In the formation of compound 1, these molecules form a hydrogen-bond with the OH group of the aldehyde, thereby greatly increasing the rate of the reaction, to a higher degree than corresponds to additivity. On the other hand, there is no chance of this with compound 5. Accordingly, the rate-reducing effect of the interaction between the amine-nitrogen and the alcohol molecules makes itself felt, and log k will be lower than the additive value. In this respect, for compounds 5 and 6 the B values in Eq. (2) decrease linearly with the activity coefficient of benzene; relationship (3) does not express a good correlation with γ_1, but with γ_2 ($b < 0$ and $r = 0.9979$ and 0.9981 for 5 and 6, respectively).

The reported results demonstrate that the aldehyde substituent significantly influences the solvent effect in the examined process.

References

[1] *Kresze, G., H. Manthey:* Z. Elektrochem. Ber. Bunsenges. Physik Chem. 58, 118 (1954)

[2] *Kresze, G., H. Goetz:* Z. Naturforsch. 7., 376 (1955).

[3] *Kresze, G., K. Becker:* Z. Naturforsch. 12, 45 (1957).

[4] *Nagy, P., Zs. Molnár:* Szegedi Tanárképző Főisk. Tud. Közl. 145 (1966).

[5] *Nagy, P.:* Szegedi Tanárképző Főisk. Tud. Közl. 153 (1966).

[6] *Nagy, P.:* Szegedi Tanárképző Főisk. Tud. Közl. 61 (1967).

[7] *Nagy, P., R. Herzfeld:* Acta Phys. et Chem. Szeged, 32, 33 (1986).

[8] *Nagy, P., R. Herzfeld:* Szegedi Tanárképző Főisk. Tud. Közl. in press

[9] *Reichardt, C., E. Harbusch-Görnert:* Liebigs. Ann. Chem. 721 (1983).

[10] *Kamlet, M.J., R.W. Taft:* J. Amer. Chem. Soc. 98, 377 (1977).

[11] *Krygowski, T.M., E. Milczarek, P.K. Wrona:* J. Chem. Soc. Perkin Trans II. 1563 (1980).

[12] *Nagy, P., R. Herzfeld:* Acta Phys. et Chem. Szeged, 31, 735 (1985).

[13] *Nagy, L., G. Schay:* Magy. Kém. Folyóirat, 70, 33 (1964).

[14] *Nagy, P., R. Herzfeld:* Acta Phys. et Chem. Szeged, 33, 53 (1987).

[15] *Landolt-Börnstein:* 6th ed., Col. 2. Part 2/a, p. 561.

[16] *Krygowski, T.M., P.K. Wrona, U. Zielkowska:* Tetrahedron, 41, 4519 (1985).

[17] "International Critical Tables", Vol. 3. p. 290, Mc.Graw-Hill.

[18] *Ezekiel, M., K.A. Fox:* "Methods of Correlation and Regression Analysis". 3rd ed., Wiley, New York, 1959.

[19] *Nagy, P.:* Acta Chim. Hung. 112, 461 (1983).

ВЛИЯНИЕ ПРИРОДЫ РАСТВОРИТЕЛЕЙ НА ОБРАЗОВАНИЕ ОСНОВАНИЙ ШИФФА

П. Надь и Р. Херцфельд

Авторами исследовано образование замещенных N-(бензилиден) анилинов. Для соединений содержащих OH группу в орто или пара положении на альдегидном кольце. Хорошая корреляция найдена между $\lg k$ и E_T^N, B_{KT}, а также коэффициентом активности более полярного компонента смеси.